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TRANSIENT BLAST LOADING

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PURPOSE

Air blast load distributions and time histories on three-dimensional structures are difficult to predict, or even estimate, with confidence. One reason is that pressures are highly transitory because of multiple reflected and transmitted pressure waves. Computational fluid dynamics can clearly be of help under these circumstances if one has confidence in the computational tool. Such confidence is generally provided by the comparison of computed results with experimental data.

In this note we present a validation calculation for the FLOW-3D computer code by applying it to the problem of a blast wave passing over a three-dimensional rectangular block. The problem selected is one for which there exists good experimental data about transient pressure distributions on the lee and aft sides of a block. This work, performed in a shock tube test facility and reported by Taylor [1], involved the passage of a 5 psi overpressure blast wave (in air) over a regular parallelopiped-shaped block.

The front face of the block was 21.27 cm in width and 10.62 cm high. The block had a depth of 7.62 cm in the direction of propagation of the blast wave (i.e., the blast wave struck the front face of the block head on). Three pressure transducers were flush mounted on the front and rear faces in locations that provide a representative sampling of the pressures over the entire surface of each face, see Fig. 1.

This problem has previously been modeled by a computer program with good results [2]. That work, however, was performed by a numerical method quite different from the method used in

FLOW-3D. In any case, the purpose here is to provide an independent validation test of FLOW-3D under conditions where shock and rarefaction waves dominate the flow.

The computational model is explained in more detail in the following section. Computational results and comparisons with experimental data are then presented and followed by a summary in a final section.

COMPUTATIONAL MODEL

Because of left-right symmetry with respect to the incident blast wave direction, only one half of the physical problem is modeled. In terms of the depth D of the block (D=7.62 cm) the computational region started 2.5 D in front of the front block face and extended 3.5 D downstream from the rear of the block. The cross section of the modeled region was 4.5 D in width and 4.5 D in height. This region is large enough that pressure wave reflections from the outer boundaries should not influence the computed pressures on the block during the first 1 ms after the blast wave hits the block. (This is based on a 1.11 ms estimated transit time for a sound wave in air over a distance of 5 D.) For comparison we note that in Ref. 2 the computational region had slightly smaller dimensions (4.35 D, 6.78 D, 4.35 D).

Plots showing the computational mesh and the placement of the block structure in the mesh are contained in Fig. 2. The mesh consisted of 19 cells in the transverse (x) direction, 29 cells in the flow (y) direction and 19 cells in the vertical (z) direction. The total number of cells, including boundary cells is 13,671. This is significantly more than the 8381 cells used in Ref. 2, although the results obtained in that work were quite good.

As in Ref. 2 we have chosen to initialize the calculations with the blast wave coinciding with the front face of the block. Assuming normal air conditions ahead of the blast (i.e., zero velocity, atmospheric pressure equal to 1.013E+6 dynes/cm^2 and a temperature of 293 Kelvin), the conditions behind the wave were taken to be:

Pressure = 1.3576E+6 dynes/cm^2,
Temperature = 318.7 Kelvin,
Velocity = 7336 cm/s.

A complete input file for this problem is given in Fig. 3. The file contains all information necessary to construct the mesh and obstacle, to set the initial flow and boundary conditions and to specify the computed output desired including pressure histories at all transducer locations.

COMPUTATIONAL RESULTS

We shall not give an extended discussion of the computed results as this has already been done in Ref. 2. Instead, we have simply reproduced the comparison plots of computed and experimental data from Ref. 2 and added the current computational results to them.

Pressure histories at three locations on the front block face are shown in Fig. 4. Overall the results are in very good agreement with both the earlier calculations and with the experimental data. Some discrepancy with the experimental data at early times (say less than 0.15 ms) is apparent. In particular, the experimental pressure histories all have a flat section, while the calculated pressures show variations above and below these flat regions. This may be a result of the inevitable numerical smoothing of shocks over a few computational cells.

At front position A, the present calculation is better than the older calculation at early times because it brackets the initial high pressure spike. Similarly, at Position C the new calculation is better than the old at late times.

Corresponding comparisons with pressure transducer data on the rear face are given in Fig. 5. For these plots the zero time corresponds to about t=0.2 ms in the calculation, which is the time the undisturbed blast wave would have reached the plane of the rear face. The comparison between calculated and experimental data is not as good as on the front surface, but still it is quite acceptable.

We see that the present calculation shows somewhat better agreement with the data at Position A than the older calculation, especially after 0.2 ms. We also note that the new calculation is not affected as early by reflected pressure waves because the boundaries have been moved further away from the block.

Figure 6 contains vector plots and pressure contours in the plane of symmetry at t=0.2 ms when the blast wave just reaches the back face, and at t=0.8 ms when the wave reaches the downstream boundary of the computational region. At the later time we can see a small recirculating eddy at the top rear corner of the block.

Finally, in Fig. 7, are plotted the time histories of the net pressure force on the (half) block in the direction of the flow and the overturning moment. The moment is large and nearly constant until the flow reaches the rear face after which the moment is significantly reduced. The net force, on the other hand, shows a monotonic decrease from its early peak value.

DISCUSSION

An earlier calculation of a blast wave passing over a rectangular block has been repeated with the FLOW-3D program. A slightly larger computational domain was used to reduce the influence of reflected pressure waves. We also employed a somewhat more refined computational grid in order to improve the numerical accuracy.

Computed results were found to be in good agreement with the experimental data and are as good or slightly better than the previous computational results.

These results serve as a useful validation test for FLOW-3D under conditions involving a strongly three-dimensional, transient flow of a compressible fluid.

The computational time required to simulate 1.0 ms of problem time was 4.12 hours on a MicroVAX II computer. On a newer DEC Station 3100 this time would be about 24 min.

References

1. Taylor, W.J., "A Method for Predicting Blast Loads during the Diffracting Phase," The Shock and Vibration Bull., NR42, 135 (1972).

2. Stein, L.R., Gentry, R.A. and Hirt, C.W., "Computational Simulation of Transient Blast Loading on Three-Dimensional Structures," Comp. Methods in App. Mech. and Eng., 11, 57 (1977).

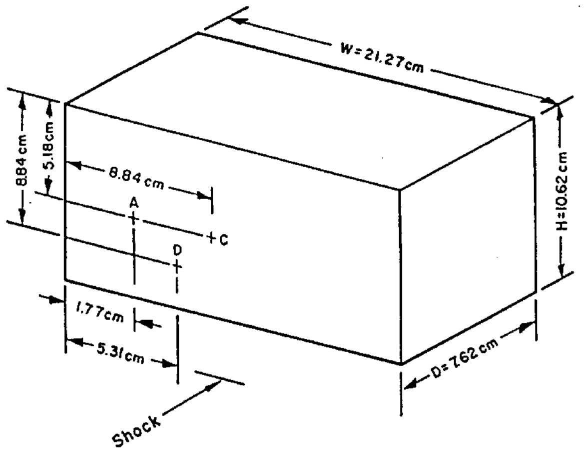
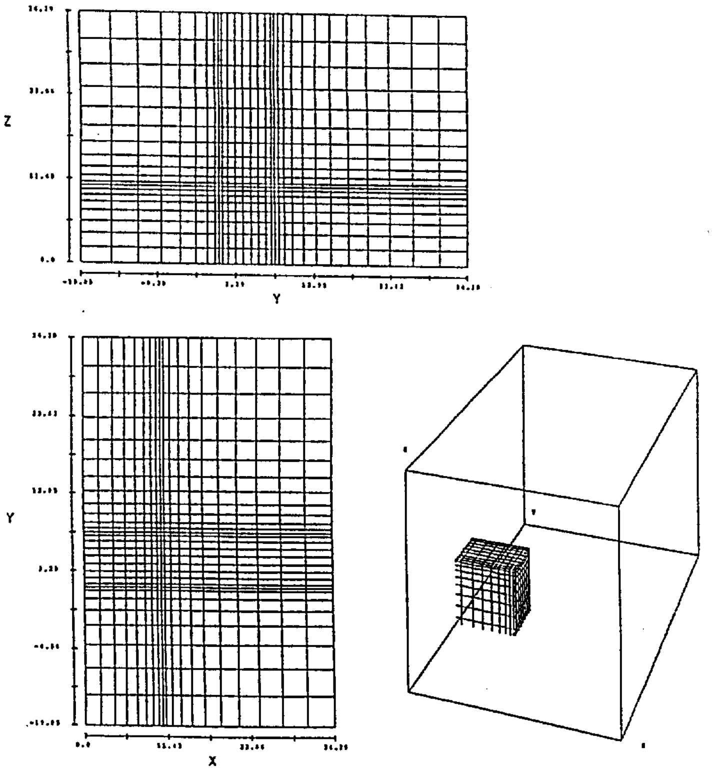


Fig. 1. Schematic of block showing pressure gage locations.

Fig. 2. Computational mesh and placement of block in mesh.



```
BLAST WAVE OVER BLOCK (TAYLOR EXPER.)
 $XPUT
    ITB=0,         ICMPRS=1,      IFENRG=2,      IFRHO=2,
    NMAT=2,        EPSI=5.0,
    CV2=7.178E+6,                 RF2=2.87E+6,
    DELT=1.0E-5, PRTDT=10.,       PLTDT=1.0E-4,  TWFIN=1.0E-3,
    WF=6,          VBCT(1,3)=7336.,      PBCT(1,3)=1.3576E+6,
                   TBCT(1,3)=318.7,      FBCT(1,3)=0.0,
    WBK=3,         FBCT(1,4)=0.0,
    IRPR=2,        JBKPR=2,       KTPR=2,
 $END
 $MESH
    NXCELT=19,
    PX(2)=10.635,     PX(3)=34.29,
    NXCELL(1)=8,      SIZEX(2)=0.5,
    NYCELT=29,
    PY(1)=-19.05,     PY(2)=0.0,     PY(3)=7.62,    PY(4)=34.29,
    NYCELL(2)=9,      SIZEY(2)=0.5, SIZEY(3)=0.5,
    NZCELT=19,
    PZ(2)=10.62,      PZ(3)=34.29,
    NZCELL(1)=8,      SIZEZ(2)=0.5,
 $END
 $OBS
    NOBS=1,
    IOFO(1,1)=1,
    CC(1)=-0.1,      XH(1)=10.635,   YL(1)=0.0,   YH(1)=7.62,
    ZH(1)=10.62,
 $END
 $FL
    NFLS=1,          PRESI=1.013E+6,
    FCC(1)=-0.1,     FYH(1)=0.0,
    FREG(1)=0.0,   . PREG(1)=1.3576E+6,     VREG(1)=7336.,
 $END
 $BF
 $END
 $TEMP
    NTMP=1,          TEMPI=293.0,
    TCC(1)=-0.1,     TYH(1)=0.0,            TREG(1)=318.7,
 $END
 $MOTN
 $END
 $GRAFIC
    NVPLTS=1,        IV2(1)=2,
    NCPLTS=1,        IC2(1)=2,
    NSPLTS=1,        KONTPS(1)=3,
    NWINF=1,
    XLOC(1)=8.865,       YLOC(1)=-0.1,          ZLOC(1)=5.44,
    XLOC(2)=1.795,       YLOC(2)=-0.1,          ZLOC(2)=5.44,
    XLOC(3)=5.325,       YLOC(3)=-0.1,          ZLOC(3)=1.78,
    XLOC(4)=8.865,       YLOC(4)=7.63,          ZLOC(4)=5.44,
    XLOC(5)=1.795,       YLOC(5)=7.63,          ZLOC(5)=5.44,
    XLOC(6)=5.325,       YLOC(6)=7.63,          ZLOC(6)=1.78,
 $END
 $PARTS
 $END
```

Fig. 3. Input file for FLOW-3D.

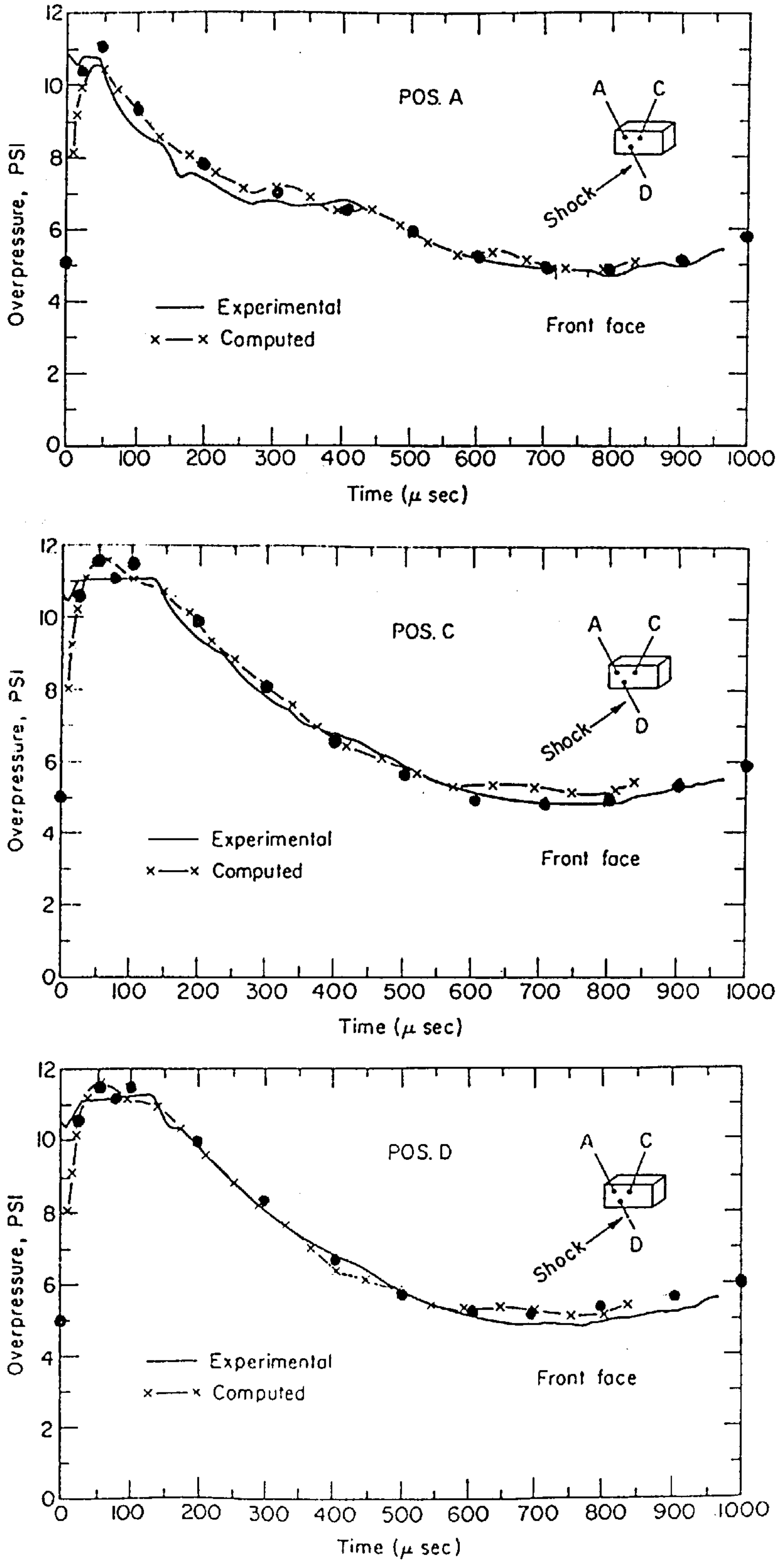


Fig. 4. Comparison of pressure histories on front face at locations A, C and D.

(FLOW-3D results indicated by ●)

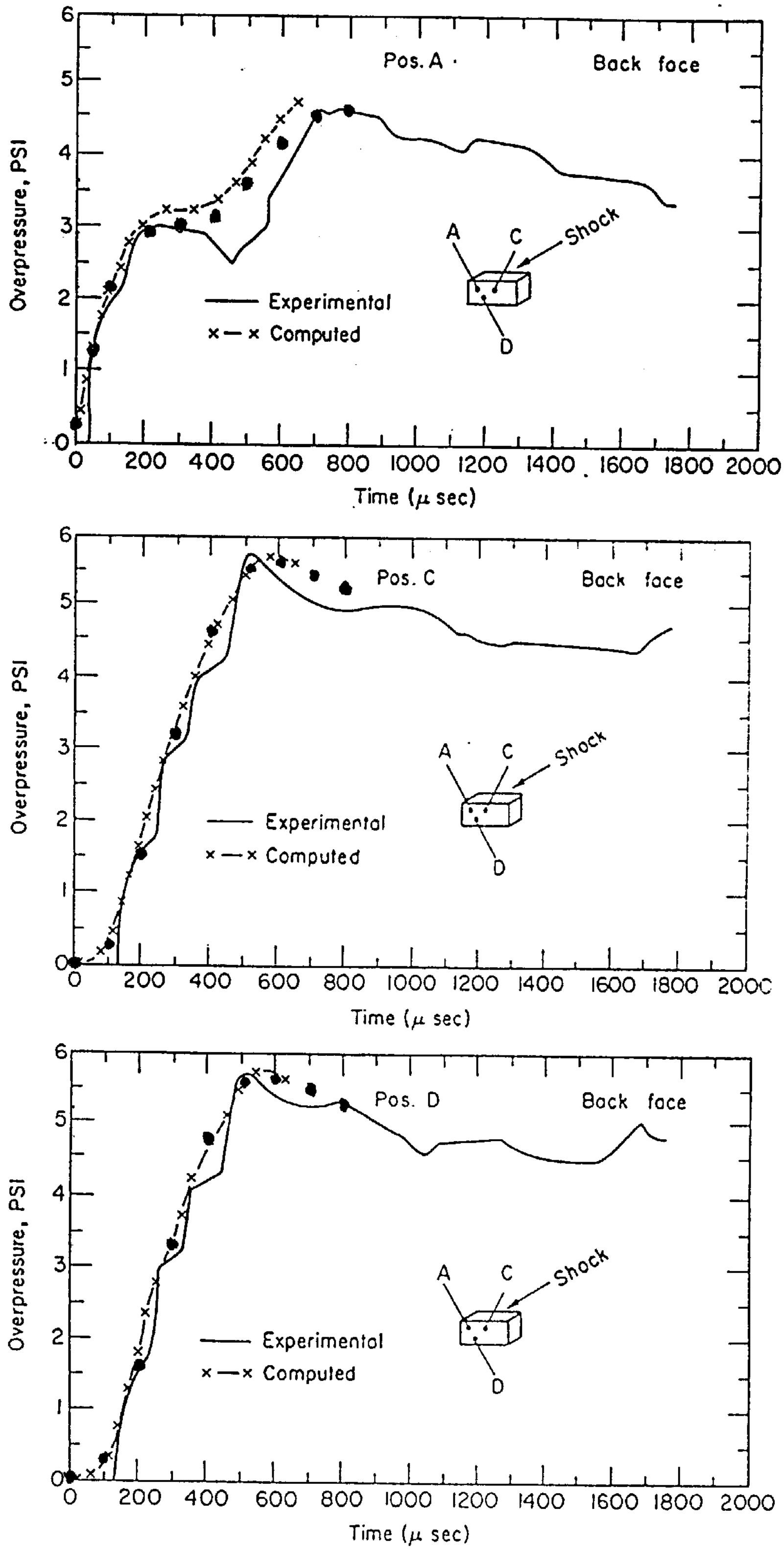


Fig. 5. Comparison of pressure histories on rear face at locations A, C and D. Zero time for these plots is 0.2 ms, which corresponds to the time the blast wave reaches the rear face.

(FLOW-3D results indicated by ●)

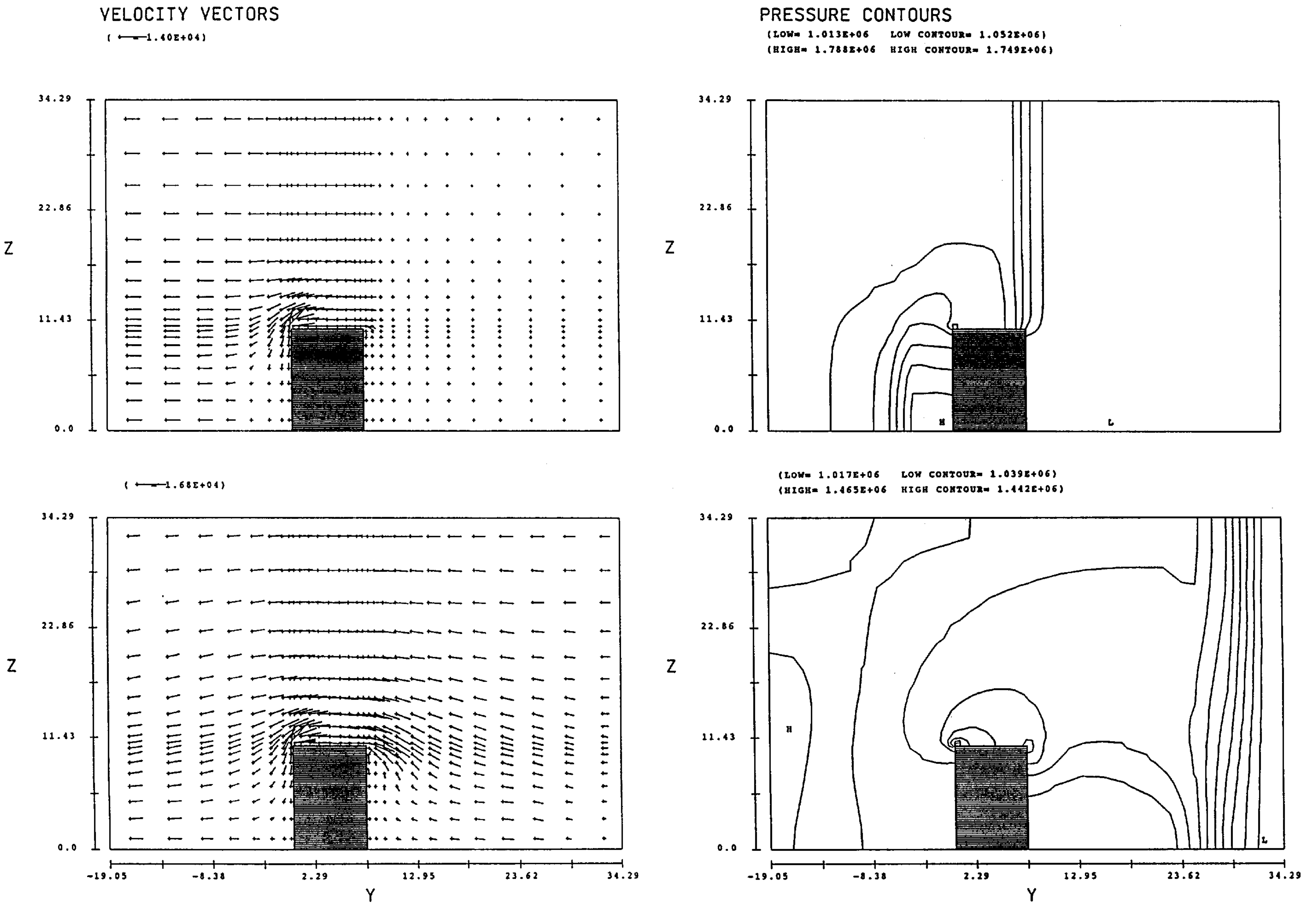


Fig. 6. Velocity vectors and pressure contours at (top) t=0.2 ms and (bottom) t=0.8 ms.

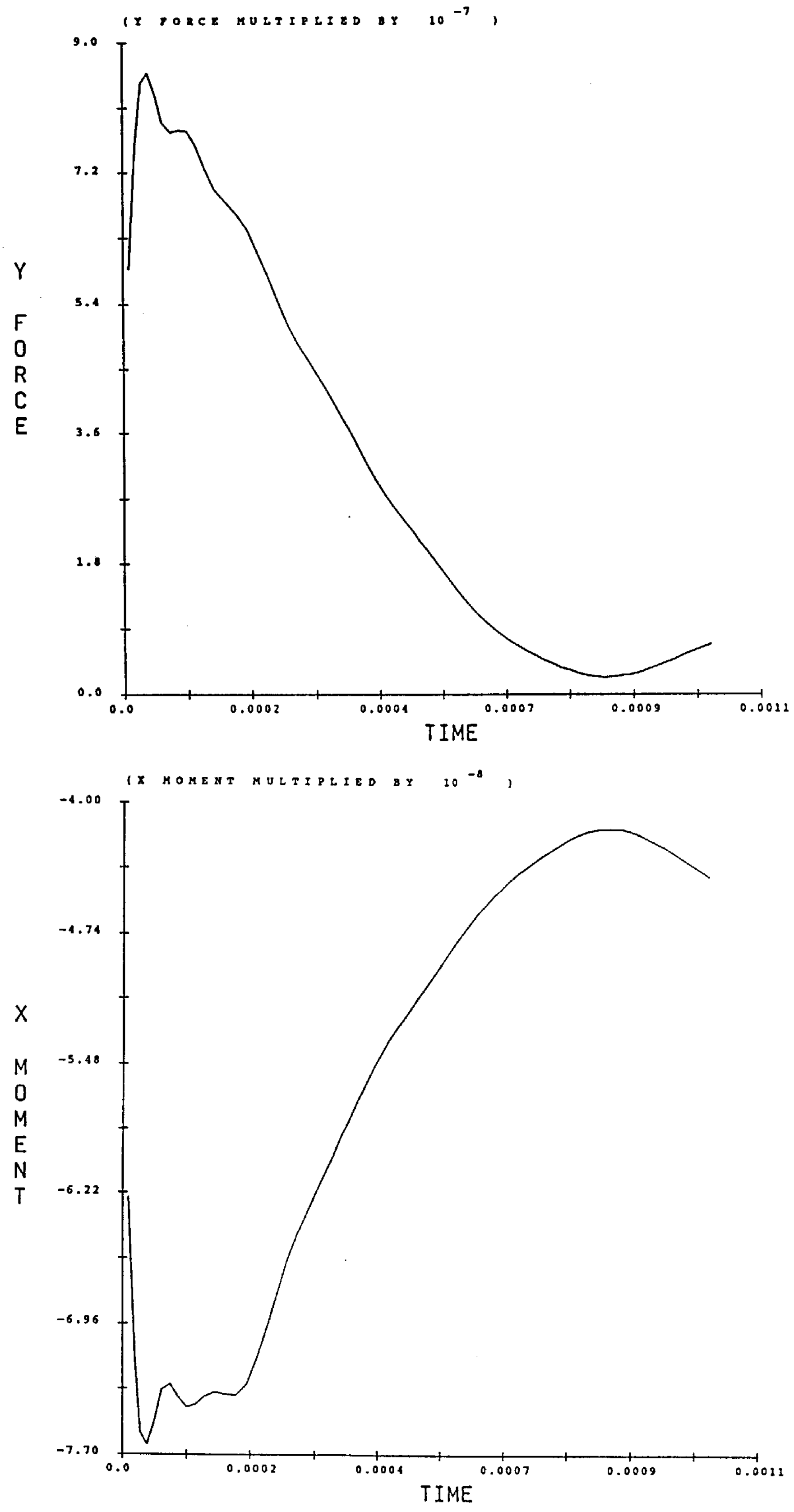


Fig. 7. Net force history on half block in direction of flow (top) and overturning moment (bottom).